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Diversity and ecology of soil algae in broadleaf sacred grove and pine forest in East Khasi Hills, Meghalaya

C. M. Dirborne✉ and Papiya Ramanujam

Algal Ecology Laboratory, Centre for Advance Studies in Botany, Department of Botany, School of Life Sciences,
North-Eastern Hill University, Shillong, Meghalaya - 793022, India
✉Correspondence author: cariedirborne@gmail.coms

मेघालय की पूर्वी खासी पहाड़ियाँ के ब्रॉडलीफ पवित्र वन और चीड़ वनों में मृदा शैवाल की विविधता और पारिस्थितिकी

सी. एम. डिरबोर्न एवं पापिया रामानुजम

सारांश

वर्तमान अध्ययन में, मेघालय के पूर्वी खासी जिले में चीड़ वन व उपोष्णकटिबंधीय चौड़े पत्ते वाले दो पृथक वनों में (मावफलांग पवित्र वन) मृदा शैवाल वर्ग की विवेचना की गई है । वन सतह में प्रकाश उपलब्धता एवं मृदा भौतिक रसायन पैरामीटर की जांच कर ली गई है । दोनों वनों से मृदा शैवाल का कुल 124 टैक्सा अभिलेखित किया गया है । क्लोरोफाइटा, जैंथोफाइसी, इयूस्टीग्मामेटोफायसी अवयव का सर्वाधिक मात्रा (72% - 80%) रहा। मावफलोंग के पवित्र वन में साइनोबेक्टेरिया का अधिक मात्रा (21%) एवं डायटम की कम मात्रा (2%) जांची गई। जबकि चीड़ के वनों में डायटम की अधिक मात्रा (20%) एवं साइनोबेक्टेरिया की कम मात्रा (13%) जांची गई । दो वनों के प्रकार में शैवाल जाति का संयोजन काफी अलग है। प्रकाश और मृदा की विशेषताओं के साथ जातियों की विविधता के बीच संबंधों से इंगित मिलता है कि पीएच. आर्द्रता की मात्रा, जैविक कार्बन एवं नाइट्रोजन के साथ वनस्पति ने शैवाल वर्ग के संयोजन में महत्वपूर्ण भूमिका निभाई है ।

ABSTRACT

In the present study, soil algal community inhabiting in two different forest types i.e., pine forest and subtropical broadleaf forest (Mawphlang sacred grove) in East Khasi Hills District of Meghalaya have been investigated. Light availability to the forest floor and soil physico-chemical parameters were examined. A total of 124 taxa of soil algae were recorded from both the forests. Members from Chlorophyta, Xanthophyceae, Eustigmatophyceae contributed the most (72%-80%). Mawphlang sacred grove was characterised by more abundance of Cyanobacteria (21%) and less diatoms (2%), while in pine forest diatoms abundance was high (20%) and less Cyanobacteria (13%). Algal species composition differed significantly between the two forest types. Correlation between species diversity with light and soil characteristics indicated that vegetation along with pH, moisture content, organic carbon and nitrogen played important role in determining the composition of algal community.

Keywords: Soil Algae, Sacred Grove, Pine Forest, Moisture Content, Diatoms

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INTRODUCTION

Algal community of soils form one of the most sensitive biotic components and play significant roles in the ecological stability of soil systems (Megharaj & al., 2000). They also form an integral part of soil ecosystems all over the world as they represent the significant autotrophic components of the biotic community of all soils. Algal community structure is influenced by specific climate condition, particular soil type and specific vegetation of the locality (Bohlen & al., 2001). Canopy cover formed by the higher plants along with the physical and chemical characteristics of the soil affected the composition of the algal population in the forest floor (Bakieva & al., 2012). Positive influences of nutrients, moisture content and the degree of soil compaction have been observed on the growth of soil algae (El-Gamal & al., 2008).

Algae of temperate soils are well explored (Fujita & Nakahara, 2006; El-Gamal & al., 2008; Mansour & Shaaban, 2010) those of certain tropical soils are also being explored recently. In tropical soils Rehakova & al., (2011) observed the influence of altitude and vegetation type on the microalgal communities in Ladakh, while the colonisation of Cyanbacteria in desert soils of Thar desert as a function of agroecological conditions was reported by Bhatnagar & al., (2008). Tropical wet soils are rich with algae unlike temperate soils where algal diversity is low (Lukesova 2001; Ray & Thomas, 2013). The current investigation on the diversity and ecology of soil algae in subtropical moist broad-leafed forest patches of Mawphlang sacred grove and pine forest in East Khasi Hills, Meghalaya, aimed to generate basic data on soil algal communities in two different forest types which represent this biodiversity hot spot region.

STUDY SITES

The present study was carried out in Mawphlang sacred grove and pine forest during 2015-2016.

Mawphlang sacred grove situated about 25 km south of Shillong is an undisturbed subtropical broad-leafed forest patch lying at an altitude of 1815 m, 25º26’N and 91º44’ E. It has been preserved and protected by the khasi tribal community and have a religious significant. The common tree species recorded from this grove are members of the genus *Castanopsis*, *Eleocarpus*, *Ficus*, *Myrica*, *Quercus* and *Symplocos*. Soil in the grove is blackish brown in colour and is of sandy loam in texture. Due to thick tree canopy in the grove very low intensity of light ranging between 41-70 µmol photons m^{-2} s^{-1} penetrated to the forest floor. Litter in forest floor of Mawphlang sacred grove is thicker as compared to pine forest mostly consist of leaves, flowers, fruits and twigs from among which the leaves form the major mass.

Subtropical pine forest in Shillong is unique and the present site was selected inside the North Eastern Hill University campus, located at an altitude of 1415 m, 25º36’N and 91º53’E. *Pinus kesiya* Royle ex Gordon is the dominant tree species in this area. Other species of *Eucalyptus* sp, *Jacaranda mimosifolia* D. Don, *Alnus nepalensis* D. Don, *Albizia* sp and *Prunus cerasoides* D. Don were also found in the surrounding forest. Pine forest soil is brownish in colour and loamy sand in texture. Pine needles form the major mass of litter in this forest along with herbaceous plants in intact form or semi decomposed condition. Open canopy in pine forest allows sufficient light to reach the forest floor with an intensity ranging from 150-350 µmol photons m^{-2} s^{-1}.

MATERIALS AND METHODS

Soil Analysis

Soil samples were collected on a monthly basis from November 2015 to October 2016. 10 random sites were selected from each forest. 500 g of soil was collected from the upper layer of the soil (0-2 cm) by removing the surface litter at each site. Soil samples were soaked in deionized water (1:5 proportions) to prepare a soil solution for the measurements of pH and electrical conductivity which were read using digital pH meter (model - 101) and conductivity meter (model - 611). Soil texture was estimated by hydrometer method (Bouyoucos, 1962). Moisture content of the soil was determined by oven dry basis (drying 10 g soil in a hot air oven at 105 ºC). Soil organic carbon was estimated following the method by Walkley & Black (1934) while total nitrogen, phosphorus and potassium were estimated as per Jackson (1967).

Algal Analysis

About 10 g of each soil sample was placed in a flask and diluted 100-fold with distilled water. Different culture media (BBM, BG-11 and Gulliard medium) in liquid or solidified form with 1.5% agar were used for culture and isolation of the algae. The number of algae appeared in culture media were determined by counting algal colonies and estimated per 1g dry weight (d.w.) of soil. Colonies of Chlorophyta (CH), Xanthophyceae (X) and Eustigmatophyceae (E) (hereinafter CH+X+E) were counted together, Cyanobacteria (CY) and Bacillariophyceae (D) were counted separately (Zancan & al., 2006).

All the isolated algae were observed under trinocular microscope (Olympus BX41) and identified to the possible lower taxonomic level by consulting standard books and monographs like Fritsch (1935), Desikachary (1959), Philipose (1967), Prescott (1982), Gandhi (1998) and John & al. (2002). Taxonomy was updated using the online database Algae Base (Guiry & Guiry, 2017) and ADIAC (Automatic Diatom Identification and Classification) Diatom image database funded by the European Marine Science and Technology (MAST) programme.

Species diversity was calculated using the Shannon-Wiener diversity index (1963) following the formulae,

$$H' = \sum_{i=1}^{s} p_i \ln p_i$$

Where $p_i = n_i/N$, n_i= number of individuals of the ith species; N= total number of individuals of all the species.

Statistical Analyses

Values for different physico-chemical parameters and algal abundance were obtained on the basis of mean of ten independent samples. The data were statistically analysed using ANOVA with Microsoft Office Excel. nMDS (nonmetric multidimensional scaling) ordination plot was incorporated to detect the similarities of algal species in the two forests. ANOSIM (Analysis of similarities) was performed to obtain the significance of difference for species composition by using Bray Curtis distance measure permutation of 9999. ANOSIM used the procedure of comparing similarity between groups whether is greater than or equal to similarity within the groups. The test statistic R is calculated as

$$R = \frac{rB - rW}{n(n-1)/4}$$

Where *rB* is the average of rank similarities from different groups, *rW* is the average of rank similarities within groups and *n* is the total number of samples. The value R ranges from -1 to +1. These analysis were carried out in PAST software version 1.93.

Principal Component Analysis (PCA) was employed to compare the two forest types with soil characteristics in the first analysis and a second analysis was conducted to compare the algal community characteristics on the abundance of taxa identified belonging to different algal classes. PCA was performed using statistical package XLSTAT version 2009.

RESULTS

Soil Characteristics

All the soil parameters, except for phosphorus varied significantly ($p < 0.05$) in two forest types. In both the forests, pH of the soil was acidic and ranged from 4.83-6.63. Moisture content and water holding capacity of soil in sacred grove were higher than the soil in the pine forest whereas soil temperature in pine forest was higher than that of sacred grove.

Organic carbon and total nitrogen were higher in sacred grove compared to that in pine forest. Organic carbon was higher during March to May while total nitrogen was higher during June to September in both the forests. Exchangeable potassium and electrical conductivity were also higher in sacred grove than in pine forest while available phosphorus was recorded to be higher in pine forest than sacred grove. Monthly variations for electrical conductivity was comparatively less in the two forest types, potassium and phosphorus were higher during June to August (Table 1 & Figure 2).

Diversity and Composition

Based on morphological characteristics, 124 algal taxa were identified from the two forests. Out of 124 taxa, 71 were recorded exclusively in sacred grove and 63 in pine forest, while only 10 taxa were noted to be common in the two forests (Table 2). Soil in the sacred grove supported diverse algal community mostly dominated by Cyanobacteria and green algal species. Pine forest revealed lesser number of taxa as compared to sacred grove, while diatoms were observed to be in abundant in this forest.

The average abundance of soil algae varied from 38 x 10^3 to 4200 x 10^3 algal cells g^{-1} soil (d.w). Members of CH+X+E accounted for high abundance (3500 x 10^3 g^{-1} soil d. w) in almost all the samples analyzed from the two forests. Cyanobacteria members were abundant in sacred grove (850 x 10^3 g^{-1} soil d. w) than in pine forest (<500 x 10^3 g^{-1} soil d. w) while diatoms were comparatively higher in pine forest

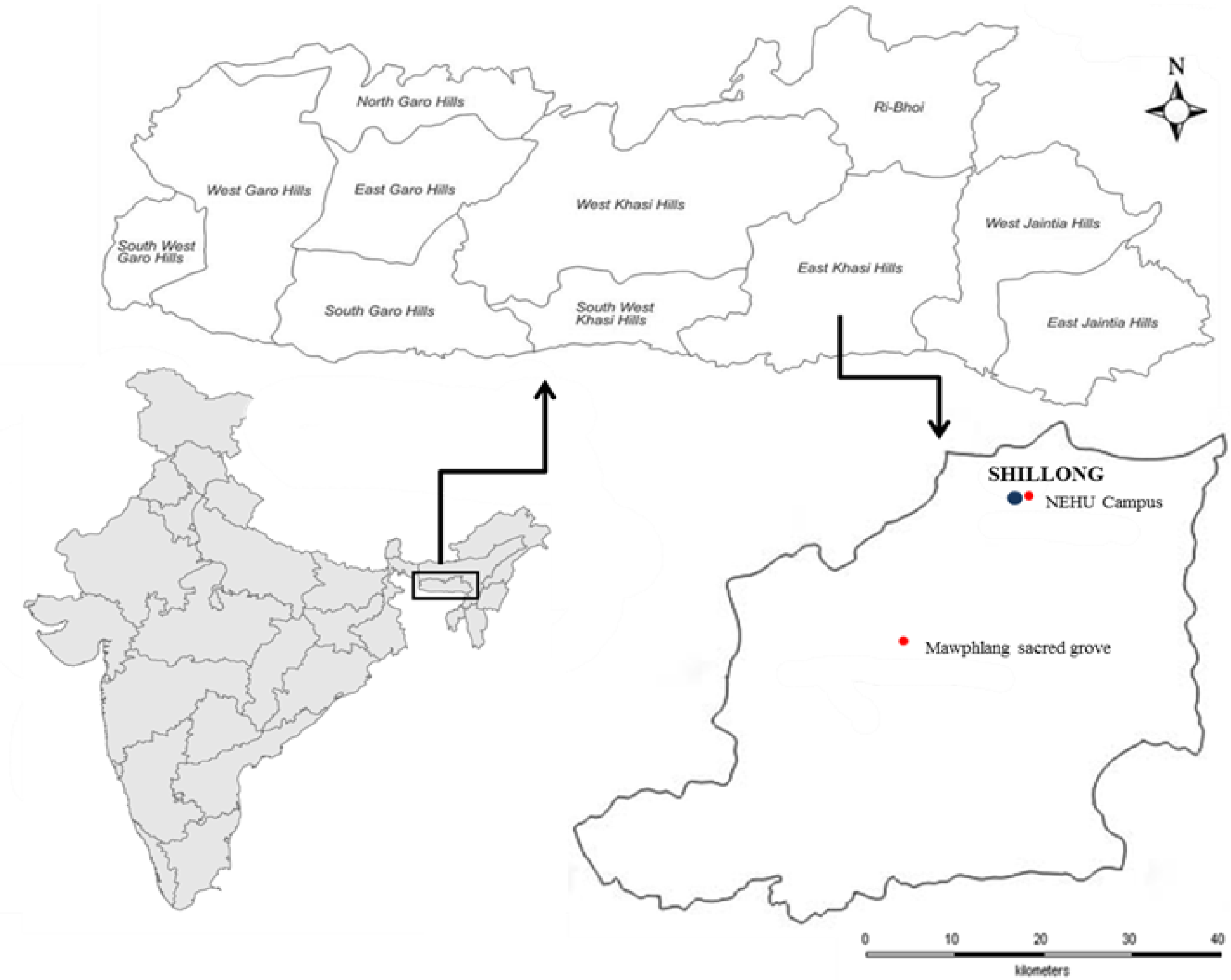

Fig. 1. Map showing location of the two forest types in East Khasi Hills District of Meghalaya

Table 1. Range of soil parameters in the sacred grove and pine forest (values in parenthesis denotes mean and standard deviation)

Parameters	Pine Forest	Sacred Grove	F-value	P-value
pH	5.15 - 6.63 (5.71±0.49)	4.83 - 5.23 (5.01±0.17)	20.95	0.0001*
Temperature (^{o}C)	14 - 32 (24.25±7.16)	8 - 24 (17.25±5.95)	6.77	0.01*
Moisture content (%)	18.98 - 42.15 (31.36±10.02)	27.12 -58.1 (46.02±11.93)	10.61	0.003*
Water holding capacity (%)	14.56 - 15.43 (15.03±0.32)	30.23 - 32.87 (31.65±0.87	3773.36	4.19E-26*
Conductivity (mS^{-1} /cm)	0.01 (0.01±1.81E-18)	0.02 (0.04±3.62-18)	17.18	0.0064*
Organic carbon (%)	0.78 - 2.56 (1.76±0.59)	1.76 - 3.98 (2.40±0.67)	6.07	0.02*
Total nitrogen (%)	0.09 - 0.18 (0.13±0.02)	0.17 - 0.29 (0.22±0.04	34.79	6.17E-06*
Available Phosphorus (%)	0.002 - 0.0067 (0.0034±0.001)	0.002 - 0.0045 (0.003±0.0009)	0.39	0.53
Exchangeable Potassium (%)	0.01 - 0.02 (0.01±0.005)	0.02 - 0.03 (0.02±0.007)	15.62	0.0006*

*Show statistical significance levels at 0.05p, 0.01p and 0.001p levels.

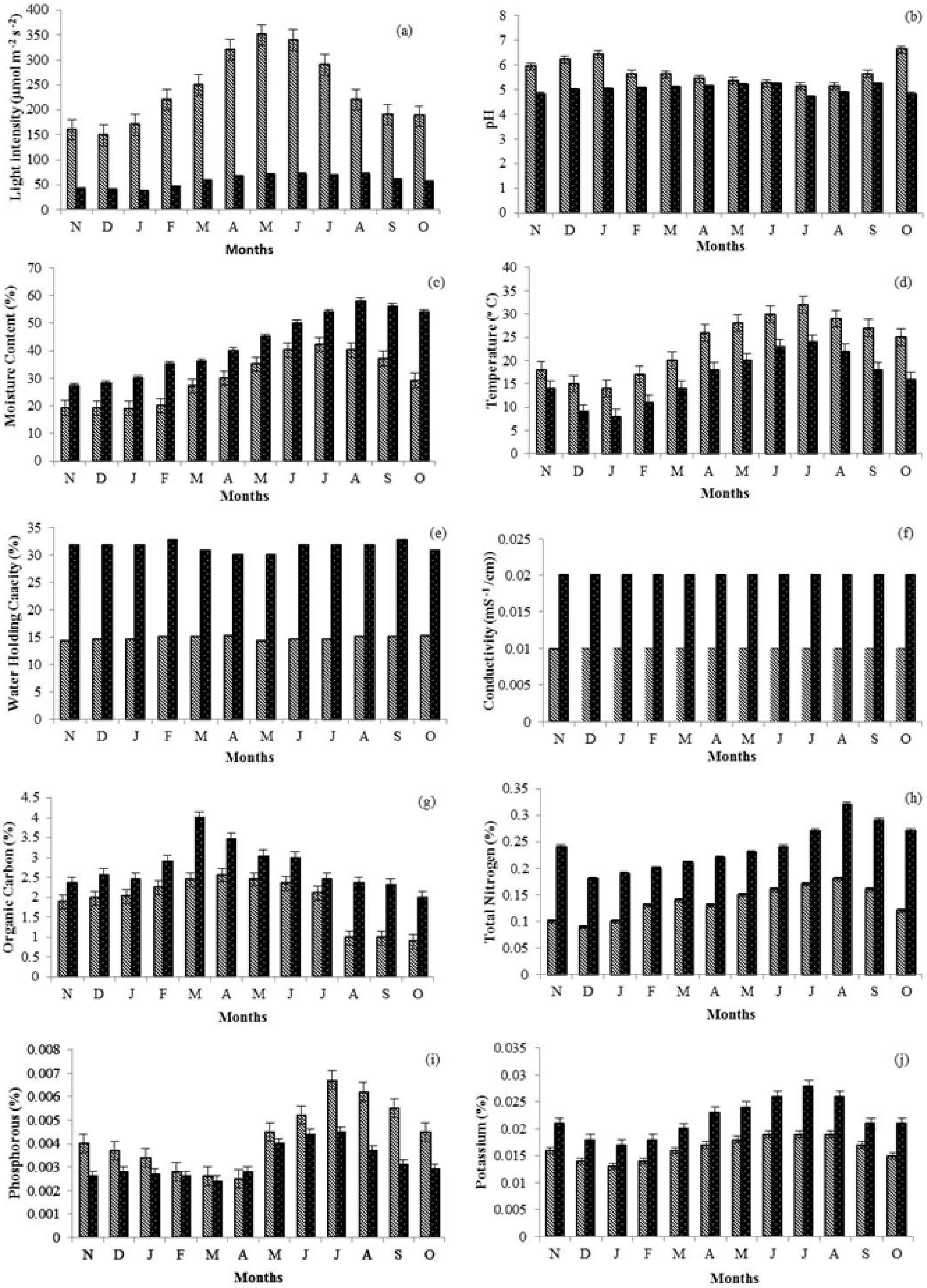

Fig. 2. Temporal and spatial variation of **(a)**. light **(b)**. pH **(c)**. moisture content **(d)**. temperature **(e)**. water holding capacity **(f)**. conductivity **(g)**. organic carbon **(h)**. total nitrogen **(i)**. phosphorous and **(j)**. potassium in two forest. (▨) indicates pine forest and (■) sacred grove.

Table 2. List of algae recorded from forest floor of sacred grove and pine forest

Name of the species	Pine Forest	Sacred Grove
Cyanobacteria		
Anabaena catenula Kützing ex Bornet & Flahault	+	+
Anabaena constricta (Szafer) Geitler	+	-
Anabaena oscillariodes Bory	-	+
Anabaena spiroides Klebahn	+	-
Aphanocapsa elachista West & G.S.West	-	+
Cylindrospermum michailovskoense Elenkin	-	+
Cylindrospermum muscicola Kützing ex Bornet & Flahault	-	+
Gloeocapsa alpina Nägeli	-	+
Gloeocapsa decorticans (A.Braun) P. Richter	+	-
Gloeothece tepidariorum (A. Braun) Lagerheim	-	+
Lyngbya lagerheimii Gomont ex Gomont	-	+
Lyngbya semiplena J. Agardh ex Gomont	-	+
Lyngbya spiralis Geitler	+	-
Microcoelous sp	-	+
Nostoc carneum C. Agardh ex Bornet & Flahault	-	+
Nostoc commune Vaucher ex Bornet & Flahault	-	+
Nostoc pruniforme C. Agardh ex Bornet & Flahault	+	-
Oscillatoria curviceps C. Agardh ex Gomont	+	-
Oscillatoria germinata Schwabe ex Gomont	-	+
Oscillatoria limosa C. Agardh ex Gomont	-	+
Oscillatoria nigra Vaucher ex Gomont	-	+
Phormidium inundatum Kützing ex Gomont	+	-
Schizothrix lateritia Gomont	-	+
Schizothrix telephoroides Gomont	+	-
Scytonema mirabile Bornet	-	+
Scytonema ocellatum Lyngbye ex Bornet&Flahault	-	+
Stigionema ocellatum Thuret ex Bornet & Flahault	-	+
Symploca muscorum Gomont ex Gomont	-	+
Synechococcus aeruginosus Nägeli	+	-
Westiellopsis sp	-	+
Bacillariophyceae		
Achnanthes lanceolata (Brébisson ex Kützing) Grunow	-	+
Achnanthidium minutissimum (Kützing) Czarnecki	-	+
Amphora elliptica (Agardh) Kützing	+	-
Cocconeis placentula Ehrenberg	-	+
Cymbella affinis Kützing	+	-
Cymbella cistula (Ehrenberg) O. Kirchner	+	-
Cymbella leptoceros (Ehrenberg) Kützing	-	+
Cymbella naviculiformis Auerswald ex Heiberg	+	-
Diadesmis contenta (Grunow) D.G. Mann	-	+
Eunotia crista-galli Cleve	+	-

Eunotia exigua (Brébisson ex Kützing) Rabenhorst	+	-
Gomphonema lanceolatum Kützing	-	+
Gomphonema olivaceum (Hornemann) Brébisson	+	-
Gomphonema parvulum (Kützing) Kützing	+	-
Hantzschia abundans Lange-Bertalot	+	+
Hantzschia amphioxys (Ehrenberg) Grunow	+	-
Luticola mutica (Kützing) D.G.Mann	+	-
Melosira varians C. Agardh	+	-
*Navicula conferva*cea (Kützing) Grunow	+	-
Navicula dicephala Ehrenberg	+	-
Navicula exigua (Gregory) Grunow	-	+
*Navicula gastrum (*Ehrenberg) Kützing	+	-
Neidium amphigomphus (Ehrenberg) Pfizer	+	-
Pinnularia hustedtii K. Mölder	-	+
Pinnularia mesolepta (Ehrenberg) W. Smith	-	+
Pinnularia substomatophora Hustedt	+	-
Surirella oregonica Ehrenberg	+	-
Surirella saxonica Auerswald ex Rabenhorst	+	-
Tabellaria fenesrata (Lyngbye) Kützing	-	+
Tryblionella parvula (W. Smith) T. Ohtsuka & Y. Fujita	+	-
Chlorophyceae		
Asterococcus superbus (Cienkowski)Scherffel	-	+
Binuclearia sp	-	+
Bracteacoccus grandis H.W.Bischoff & Bold	-	+
Bracteacoccus minor (Schmidle) ex Chodat	+	+
Chlamydomonas deasonii Ettl	-	+
Chlamydomonas snowiae Printz	-	+
Chlorococcum acidum P.A. Archibald & Bold	+	+
Chlorococcum echinozygotum Starr	-	+
Chlorococcum sp	+	+
Chlorolobion braunii (Nägeli) Komarek	-	+
Chlorosarcinopsis gelatinosa Chantanachat & Bold	-	+
Chlorosarcinopsis sp	-	+
Coelastrella terestris (Reisigl) Hegewald & N. Hanagata	+	+
Elliptochloris bilobata Tschermak-Woess	-	+
Gloeocycis ampla (Kützing) Rabenhorst	+	-
Gloeocystis polydermatica (Kützing) Hindak	+	+
Gloeocystis vesiculosa Nägeli	+	-
Leptosira sp	+	-
Microspora floccosa (Vaucher) Thuret	-	+
Microspora pachyderma (Wille) Lagerheim	+	-
Microspora tumidula Hazen	+	-
Neospongiococcum granatum Deason	-	+
Neospongiococcum vacuolatum Deason & E.R.Cox	-	+

Scenedesmus abundans (O.Kirchner) Chodat	-	+
Scenedesmus arcuatus (Lemmermann) Lemmermann	+	-
Scenedesmus bijuga Kützing	-	+
Scenedesmus dimorphus (Turpin) Kützing	-	+
Scenedesmus quadricauda (Turpin) Brébisson	-	+
Scotiellopsis oocystiformis (J.W.G.Lund)Puncocharova & Kalina	-	+
Tetracystis pulchra R.M.Brown & Bold	+	-
Tetraspora lacustris Lemmermann	-	+
Trebouxiophyceae		
Chlorella saccharophila (Krüger) Migula	+	-
Chlorella vulgaris Beyerrinck (Beijerinck)	+	-
Dictyochloropsis splendida Geitler	-	+
Monoraphidium contortum (Thurut) Komarkova-Legnerova	+	-
Monoraphidium graffithii (Berkeley) Komarkova-Legnerova	+	-
Monoraphdium tortile (West & G .S. West)	+	-
Muriella decolour Vischer	+	-
Myrmecia bisecta Reisigl	-	+
Oocystis borgei J. W. Snow	+	-
Oocystis elliptica West	+	+
Oocystis lacustris Chodat	+	-
Podohedra saltans J. Neustupa	-	+
Pseudococcomyxa simplex (Mainx) Fott	+	-
Stichococcus bacillaris Nägeli	+	-
Trebouxia arboricola Puymaly	-	+
Klebsormidiophyceae		
Klebsormidium crenulatum (Kützing) Lokhorst	+	+
Klebsormidium elegans Lokhorst	-	+
Klebsormidium flaccidum (Kützing) P.C.Silva, K.R.Mattox & W.H.Blackwell	+	+
Klebsormidium fluitans (F.Gay) Lokhorst	+	-
Klebsormidium nitens (Kützing) Lokhorst	+	-
Zygnematophyceae		
Cosmarium variolatum P. Lundell	-	+
Cylindrocystis brebissonii (Ralfs) De Bary	-	+
Mesotaenium macrococcum (Kützing ex Kützing) J. Roy & Bisset	-	+
Mougeotia parvula Hassall	+	-
Euglenophyceae		
Euglena gracilis G. A Klebs	-	+
Euglena hemichromata Skuja	-	+
Euglena oxyuris Schmarda	-	+
Ulvophyceae		
Cladophora glomerata (Linnaeus) Kützing	-	+
Ulothrix minuta K. R Mattox and Bold	-	+

Ulothrix tenerrima (Kützing) Kützing	+	-
Eustigmatophyceae		
Eustigmatos vischeri D. J Hibberd	-	+
Xanthophyceae		
Tribonema viride Pascher	+	-
Xanthonema quadrata (Pascher) P.C. Silva	+	-

(+ indicates presence, - indicates absence

Table 3. Pearson's Correlation coefficient (r) values obtained between different algal class diversity with light and different soil parameters. (CH+X+E- Chlorophyta+ Xanthophyceae+ Eustigmatophyceae), CY- Cyanobacteria and D-Bacillariophyceae)

Parameters	Diversity index		
	CH+X+E	D	CY
Light intensity	-0.74*	0.74*	-0.63*
pH	-0.49*	0.48*	-0.37
Temperature	-0.20	0.67*	0.03
Water holding capacity	0.73*	-0.81*	0.67
Moisture content	0.57*	-0.28	0.66*
Conductivity	0.29	-0.53	0.32
Carbon	0.36	-0.22	0.58*
Nitrogen	0.54*	-0.66*	0.57*
Phosphorus	-0.37	-0.07	-0.36
Potassium	0.46	-0.66*	0.22

*Indicates significant at p<0.05

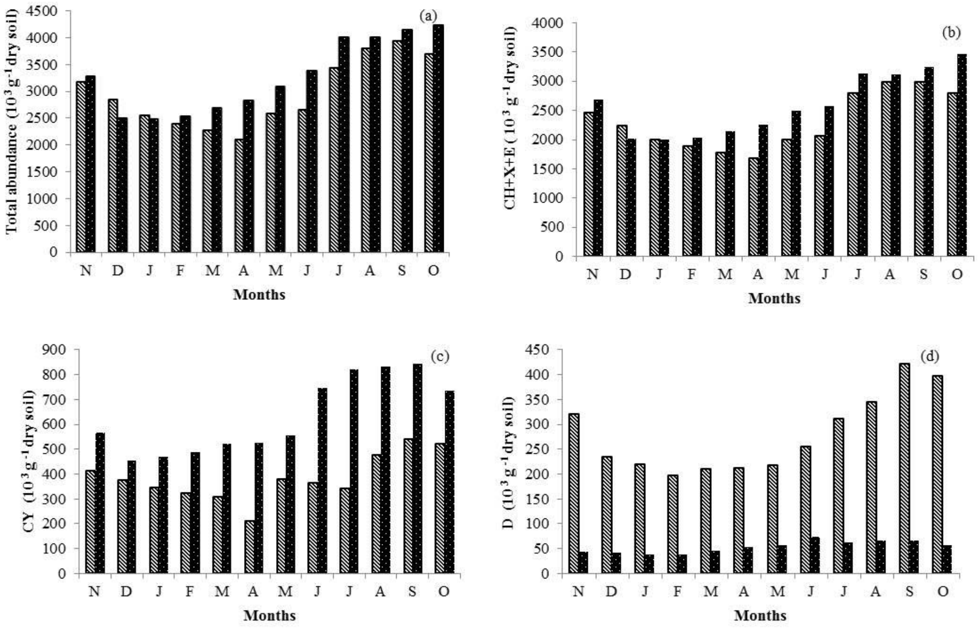

Fig. 3. Algal abundance in pine forest (▨) and sacred grove (■). **(a)**. total algal abundance **(b)**. abundance of CH+X+E (green algae+Xanthophyceae+Eustigmatophyceae) **(c)**. abundance of CY (Cyanobacteria) **(d)**. abundance of D (Bacillariophyceae).

(<450 x 10^3 g^{-1} soil d. w). Diatoms were less abundant in soil of sacred grove (<50 x 10^3 g^{-1} soil d. w) and rare during December and January (Fig. 3). In sacred grove, members of CH+X+E contributed about 80% of the total abundance of the algal community distributed throughout the year, while Cyanobacteria accounted for 18%-21 % and diatoms contributed less than 2% to the algal community structure. In pine forest CH+X+E amounted for 72%-80%, Cyanobacteria of 12%-14% while diatom members contributed 15%-25% throughout the year.

Overall diversity was higher in sacred grove in the range of 2.81-3.54 compared to that of 2.36-3.00 in pine forest. Sacred grove was recorded to have higher CH+X+E algal diversity of 2.39-3.07 than pine forest of 1.44-2.35. Cyanobacteria diversity in sacred grove varied from 1.93-2.75 while in pine forest it varied from 1.55-2.21. Diatoms diversity on the other hand was higher in pine forest with 1.75-2.38 compared to that in sacred grove with 0.99-1.74 (Fig. 4).

Application of nMDS ordination, clustered the samples from into two different groups clearly indicating that the species composition in the two forest types were different from each other. The algal community in both the forest types occupied large ordination space which could be due to the diverse algal composition (Fig. 5). ANOSIM showed significant difference in species composition (mean rank within groups = 70.81, mean rank between groups = 200.5, R = 0.94 and p = 0.0001).

The algal community in sacred grove could be distinguished from that in pine forest by the presence of species like *Binuclearia* sp, *Scotiellopsis oocystiformis*, *Eustigmatos vischeri*, *Cladophora glomerata*, *Trebouxia arboricola*, *Chlorosarcinopsis gelatinosa*, *Elliptochloris bilobata*, *Neospongiococcum vacuolatum, Euglena oxyuris, Euglena gracilis* Cyanobacteria like *Stigionema ocellatum, Scytonema ocellatum, Lyngbya semiplena, Oscillatoria limosa, and Westiellopsis* sp. Diatoms like *Achnanthes lanceolata*, *Achnanthidium minutissimum, Cocconeis placentula and Diadesmis contenta* were mostly observed. Species of *Amphora elliptica, Luticola mutica, Pinnularia substomatophora, Neidium amphigomphus, Tryblionella parvula, Klebsormidium nitens, Tetracystis pulchra*, *Pseudococcomyxa simplex and Stichococcus bacillaris* were more abundant in pine forest.

Algal Community and Soil Variables

Correlation between CH+X+E diversity index with light and different soil parameters showed a significant positive correlation with water holding capacity and moisture content and negative correlation with light intensity and pH. Cyanobacteria diversity index showed a significant positive correlation with moisture content, carbon and nitrogen. A significant positive correlation was obtained between diversity of diatoms and light intensity, pH and temperature, while negative correlation observed with water holding capacity, nitrogen and potassium (Table 3).

Principal Component Analysis (PCA) employed to compare the soil characteristics of two forest types accounted for 70% variation. Sacred grove soil could be distinguished from pine forest soil with higher water holding capacity and higher organic carbon, total nitrogen, potassium and phosphorus content. The first principal component analysis represented 48% of the total variable which primarily reflected the effect of water holding capacity, moisture content, organic carbon, total nitrogen, phosphorus, potassium and electrical conductivity while the second PC (22%) reflected the effect of temperature and light intensity. The third PC (not shown) reflected the pH. The first two components of the variance analysis based on algal community variables justified 64% of the variance in the data. In this analysis pine forest were grouped together because of limited number of Cyanobacteria and a higher number of diatoms in all the months. The intra-sites difference was greater in sacred grove than in pine forest (Fig. 6).

DISCUSSION

In both the forest types, pH of the soil was acidic. Chiu & al., (2005) reported that acidity of forest soil could be due to nature of organic matter and parent rock material. Higher amount of moisture in a soil depends on relatively dense shade (Kara & Bolat, 2008), abundant vegetation and thick layer of litter add to lower of soil temperature (Devi & Dkhar, 2014), thus the decrease of soil moisture content and increase of temperature in pine forest compared to sacred grove maybe due to this fact. Radhapriya & al., (2013) reported that dense canopy along with higher input of litter resulted in maximum storage of carbon and nitrogen in the mineral soil. This could explain the presence of higher amount of organic carbon and total nitrogenin sacred grove compared to that in pine forest throughout the sampling months. Ollinger & al., (2002) reported potential influence of vegetation on soil moisture and nutrient content through many pathways.

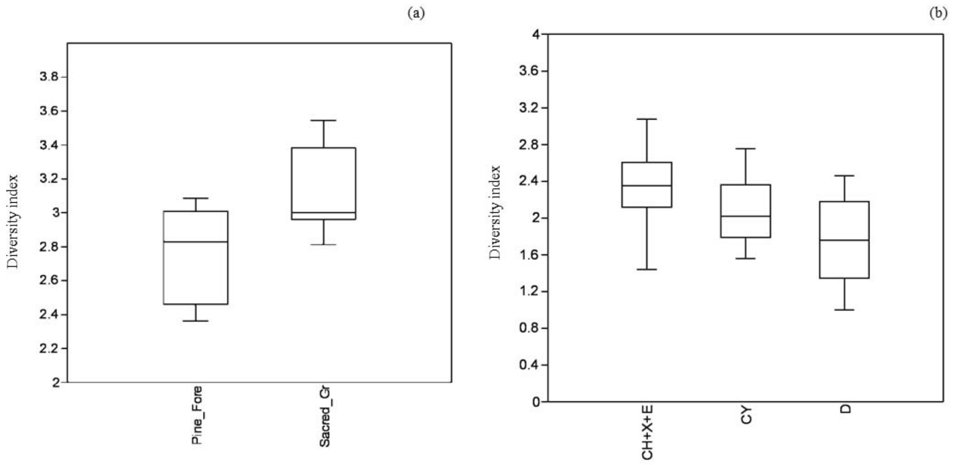

Fig 4. Boxplot of Shannon diversity index **(a)** pine forest and sacred grove **(b)**. CH+X+E (Chlorophyta+Xanthophyceae+Eustigmatophyceae), CY (Cyanobacteria) and D (Bacillariophyceae).

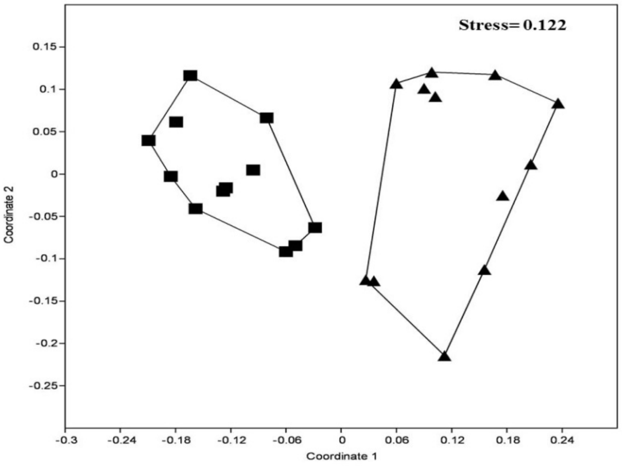

Fig 5. nMDS ordination diagram of the two forest according to species composition. Square (■) indicates pine forest and triangle (▲) signifies sacred grove.

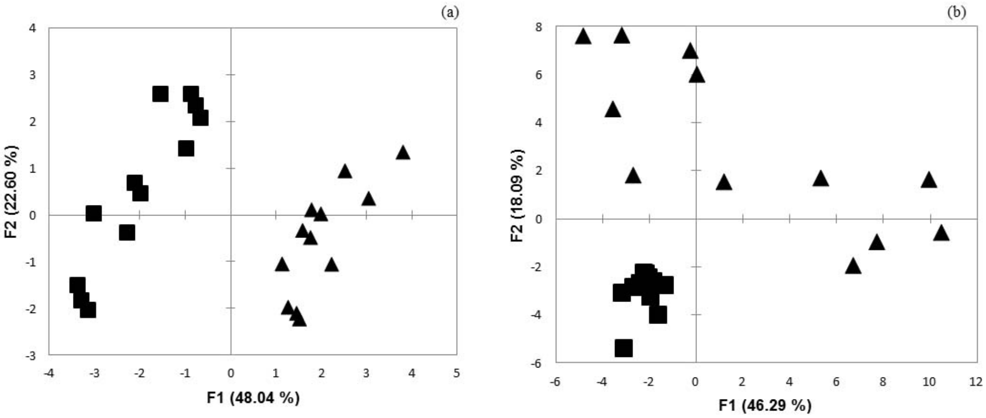

Fig. 6. Ordination diagram based on **(a)**. light intensity, pH, temperature, moisture content, water holding capacity, conductivity, organic carbon, total nitrogen, potassium and phosphorous **(b)**. algal community variables, total algal abundance, CH+X+E (Chlorophyta+Xanthophyceae+Eustigmatophyceae), CY (Cyanobacteria) and D (Bacillariophyceae. Square (■) indicates pine forest and triangle (▲) signifies sacred grove.

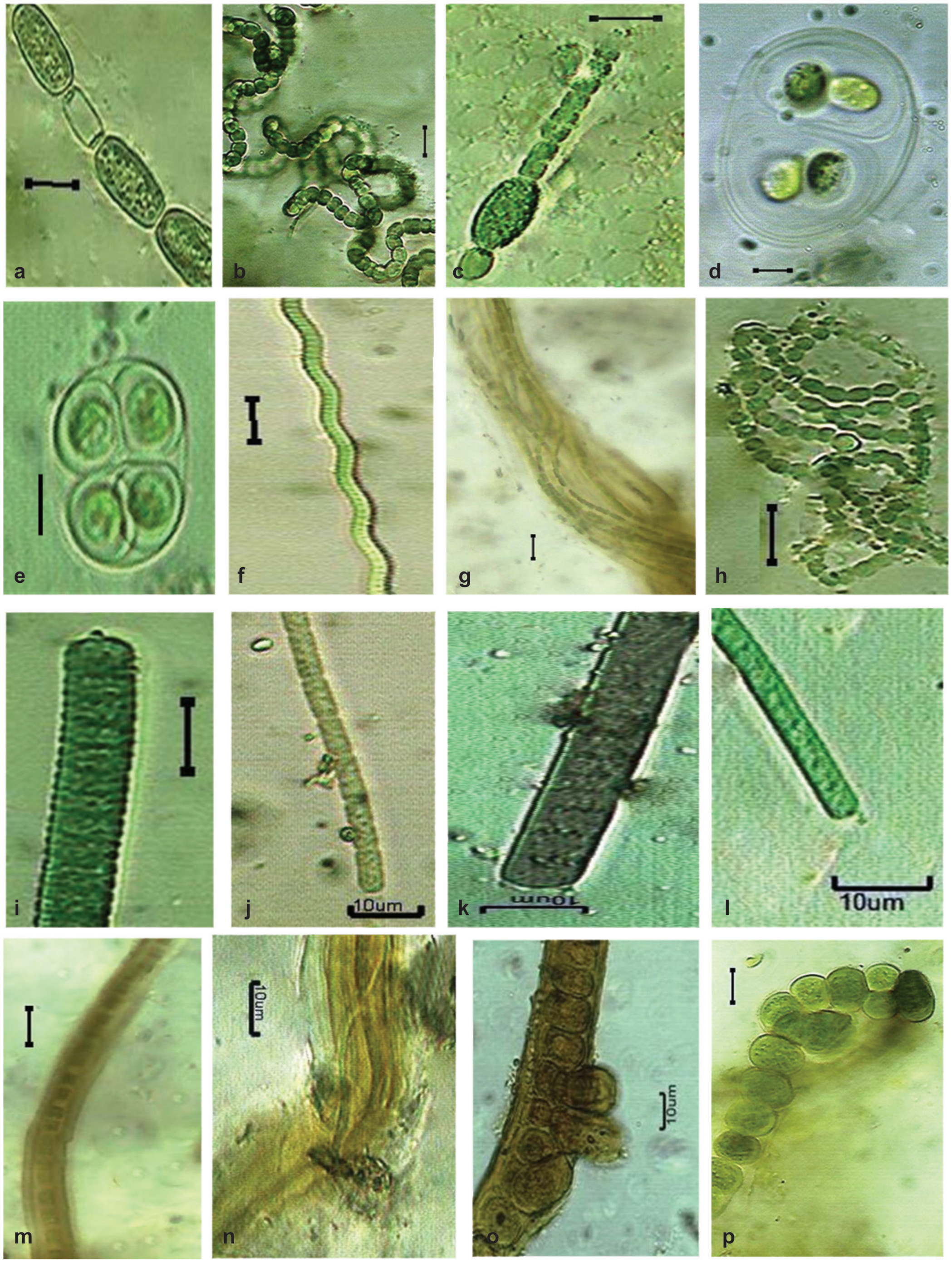

Plate 1. Cyanobacteria **a.** *Anabaena oscillariodes* Bory; **b.** *Anabaena spiroides* Klebahn; **c.** *Cylindrospermum muscicola* Kützing ex Bornet & Flahault; **d.** *Gloeocapsa alpina* Nägeli; **e.** *Gloeocapsa decorticans* Kützing ex Bornet & Flahault; **f.** *Lyngbya lagerheimii* Gomont ex Gomont; **g.** *Microcoelous* sp; **h.** *Nostoc carneum* C. Agardh ex Bornet & Flahault; **i.** *Oscillatoria curviceps* C. Agardh ex Gomont; **j.** *Oscillatoria germinata* Schwabe ex Gomont; **k.** *Oscillatoria limosa* C. Agardh ex Gomont; **l.** *Oscillatoria nigra* Vaucher ex Gomont; **m.** *Schizothrix lateritia* Gomont; **n.** *Schizothrix telephoroides* Gomont; **o.** *Stigionema ocellatum* Thuret ex Bornet & Flahault; **p.** *Westiellopsis* sp. (Scale bar - 10 µm).

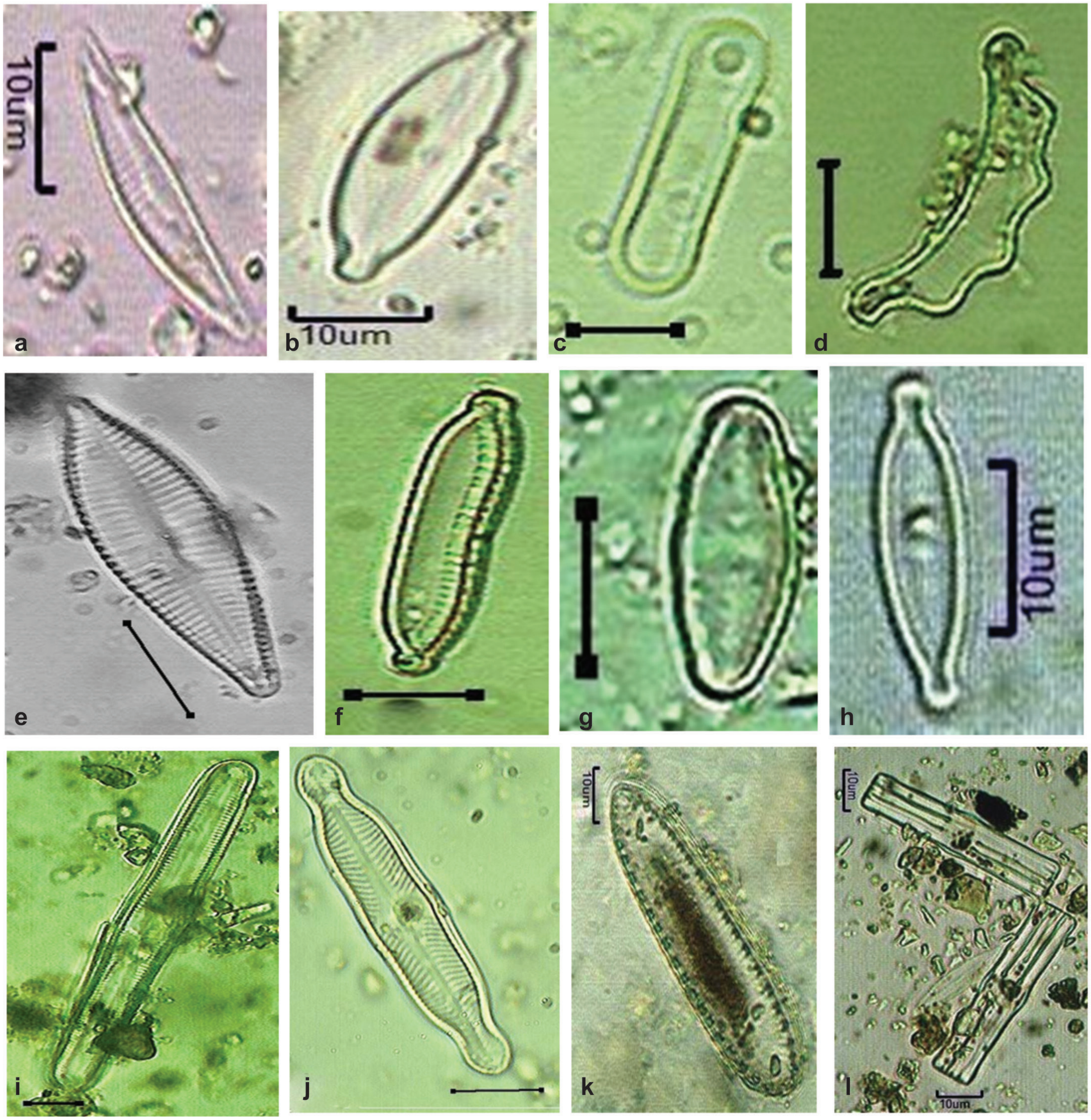

Plate 2. Bacillariophyceae: **a.** *Cymbella affinis* Kützing; **b.** *Cymbella naviculiformis* Auerswald ex Heiberg; **c.** *Diadesmis contenta* (Grunow) D.G. Mann; **d.** *Eunotia crista-galli* Cleve; **e.** *Gomphonema parvulum* (Kützing) Kützing; **f.** *Hantzschia amphioxys* (Ehrenberg) Grunow; **g.** *Luticola mutica* (Kützing) D.G. Mann; **h.** *Navicula exigua* (Gregory) Grunow; **i.** *Pinnularia hustedtii* K. Mölder; **j.** *Pinnularia mesolepta* (Ehrenberg) W. Smith; **k.** *Surirella saxonica* Auerswald ex Rabenhorst; **l.** *Tabellaria fenesrata* (Lyngbye) Kützing. (Scale bar - 10 µm).

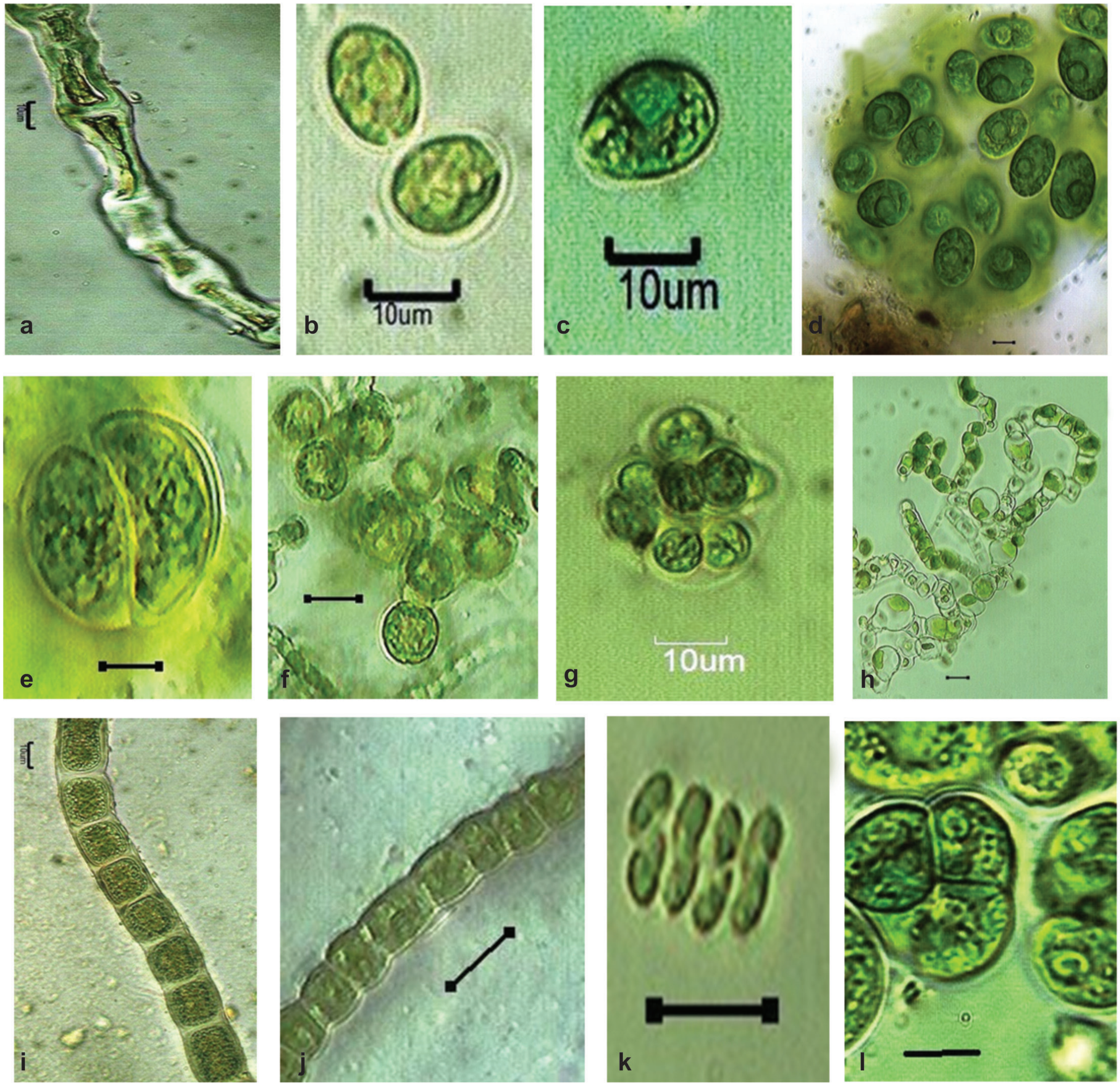

Plate 3. Chlorophyceae: **a.** *Binuclearia* sp; **b.** *Chlamydomonas deasonii* Ettl; **c.** *Chlamydomonas snowiae* Printz; **d.** *Chlorococcum sp;* **e.** *Chlorosarcinopsis* sp; **f.** *Elliptochloris bilobata* Tschermak-Woess; **g.** *Gloeocystis vesiculosa* Nägeli; **h.** *Leptosira* sp; **i.** *Microspora floccosa* (Vaucher) Thuret; **j.** *Microspora tumidula* Hazen; **k.** *Scenedesmus arcuatus* (Lemmermann) Lemmermann; **l.** *Tetracystis pulchra* R.M. Brown & Bold. (Scale bar - 10 µm).

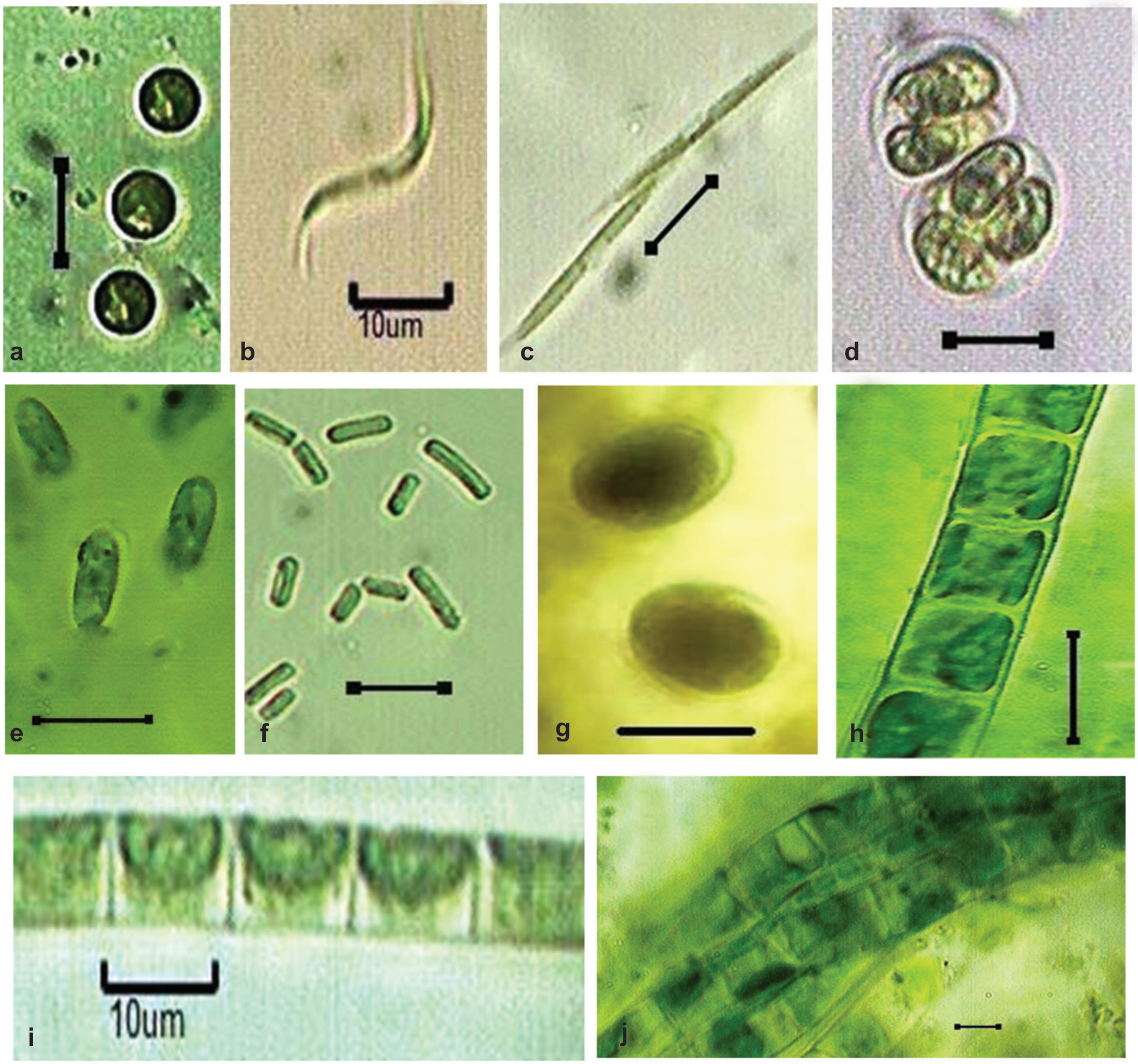

Plate 4. Trebouxiophyceae: **a.** *Chlorella vulgaris* (Beyerrinck)Beijerinck; **b.** *Monoraphidium contortum* (Thurut) Komarkova-Legnerova; **c.** *Monoraphidium graffithii* (Berkeley) Komarkova-Legnerova; **d.** *Oocystis lacustris* Chodat; **e.** *Pseudococcomyxa simplex* (Mainx) Fott; **f.** *Stichococcus bacillaris* Nägeli; **g.** *Trebouxia arboricola* Puymaly. Klebsormidiophyceae: **h.** *Klebsormidium crenulatum* (Kützing) Lokhorst; **i.** *Klebsormidium flaccidum* (Kützing) P.C. Silva; **j.** *Klebsormidium fluitans* (F. Gay) Lokhorst. (Scale bar - 10 µm).

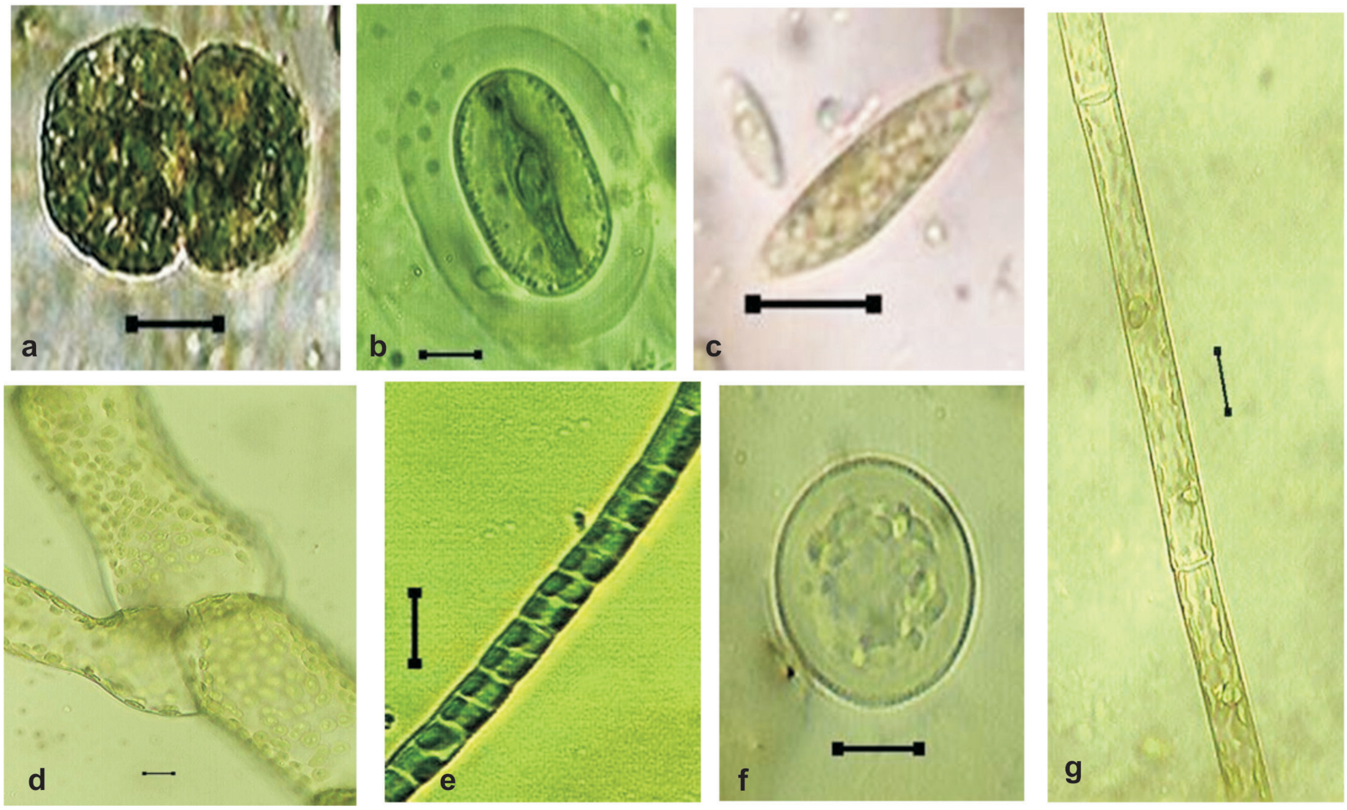

Plate 5. Zygnematophyceae: **a.** *Cosmarium variolatum* P. Lundell: **b.** *Mesotaenium macrococcum* (Kützing ex Kützing) J. Roy & Bisset; Euglenophyceae: **c.** *Euglena gracilis* G. A Klebs.; Ulvophyceae: **d.** *Cladophora glomerata* (L.) Kützing; **e.** *Ulothrix tenerrima* (Kützing) Kützing; Eustigmatophyceae: **f.** *Eustigmatos vischeri* D. J Hibberd.; Xanthophyceae: **g.** *Tribonema viride* Pascher. (Scale bar - 10 µm).

According to Neustupa & Skaloud (2008, 2010) diversity is more in open areas where light is the main influence, but observations by Ray & Thomas, (2013) revealed that in teak plantations where trees remain leafless and the soil getting more exposed to sun light, a corresponding increase in soil algal diversity was not observed. Kharkongor & Ramanujam, (2014) observed higher algal diversity in forests with closed canopy which is in conformity with the present observation that soil in the sacred grove with dense canopy supported diverse algal community mostly dominated by Cyanobacteria and green algal species. In the present study, higher soil moisture content in soil of sacred grove with dense canopy and higher carbon and nitrogen content harboured higher algal diversity as compared to pine forest.

Green algae were considered to be the most tolerant group to adverse soil conditions (Hoffmann & al., 2007), however diverse species of these algae were observed in natural forest soil (Ray & Thomas, 2013). Higher diversity of green algae in the present study was observed in more acidic and undisturbed sacred grove. pH is one of the most important factor affecting distribution of soil algae (Nayak & Prasanna, 2007). It was reported that Cyanobacteria preferred neutral to alkaline conditions of the soil (De 1939) but in the present case, many species of Cyanobacteria were observed in acidic soil of sacred grove which could be attributed to high moisture content in the soil. Higher soil moisture content in the forest favours the algal growth and is the primary factor that determines blue green algae diversity in soil (Nisha & al. 2007). Acidic nature of the soil on the other hand influenced the structure of diatom community. Diatoms species in sacred grove were very less compared to pine forest clearly supporting the fact that soil diatoms preferred to live in alkaline to neutral pH soil (Ray & Thomas, 2013).

CONCLUSION

The present study on diversity and ecology of soil algae in the two forest types, pointed out that soil in undisturbed broadleaf forest supported more diverse algal species than in pine forest. Green algal members (Chlorophyta) were the most dominant group in both the forest. In Mawphlang sacred grove, Cyanobacteria were another major contributor. Less number as well as abundance of diatoms was observed in undisturbed sacred grove as compared to pine forest which agrees with Heger & al. (2011) that the diversity of diatom is much lower in undisturbed terrestrial environment. On the other hand pine forest shows higher proportion of diatoms than Cyanobacteria. The structure of soil algal communities in the two forest types thus is the result of the complex influence of vegetation and characteristics of soil in the forest floor.

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